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(22) Date of filing : 26.06.1990

(71) Applicant : COPAL CO LTD

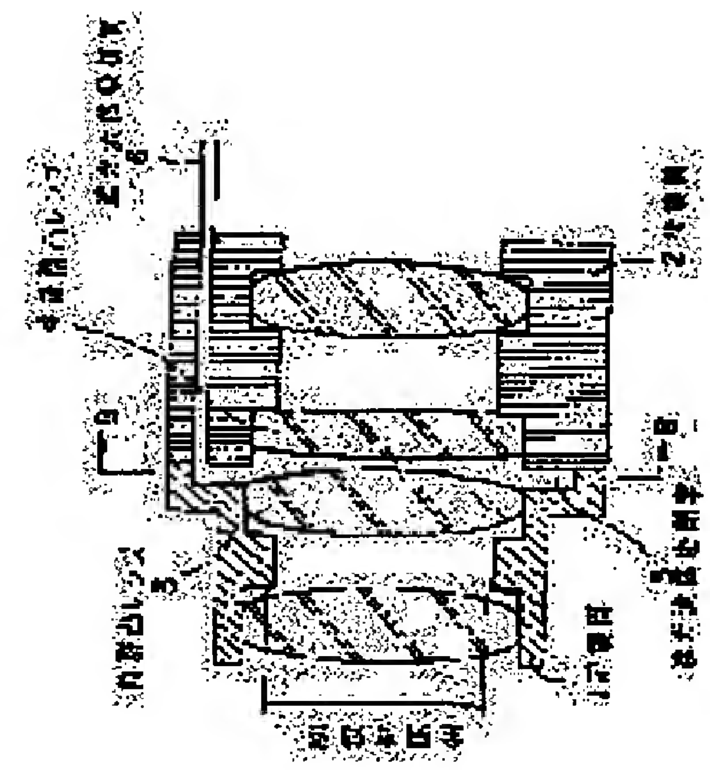
(72) Inventor : TAKAHASHI TAMOTSU

(54) CAMERA SHUTTER DEVICE USING LIGHT SHIELDING FLUID

(57) Abstract:

PURPOSE: To miniaturize a compact camera by adsorbing and discharging light shielding fluid for a sealed gap enclosed with a pair of lenses and that of lens- barrels.

CONSTITUTION: A sealed room 5 is formed with the confronting planes of a pair of convex lenses 3, 4 and the side wall parts of a pair of lens-barrels 1, 2, and a light shielding fluid adsorbing/discharging tube 6 formed along the side wall of the rear lens-barrel 2 is communicated with the sealed room 5. The sealed gap 5 is packed completely with the light shielding fluid in a state where a shutter is closed, and incident light passing a lens aperture is absorbed by the light shielding fluid, and is cut off perfectly. Thence, when the exposure operation of a camera is performed, the light shielding fluid is adsorbed from the sealed gap 5 by operating an adsorbing/discharging means. Thereby, since a shutter device can be formed in space enclosed with the pair of lenses 3, 4 and that of lens-barrels 1, 2, it follows that the major diameter of the shutter coincides with that of the lens-barrel, which enables the camera to be remarkably miniaturized.



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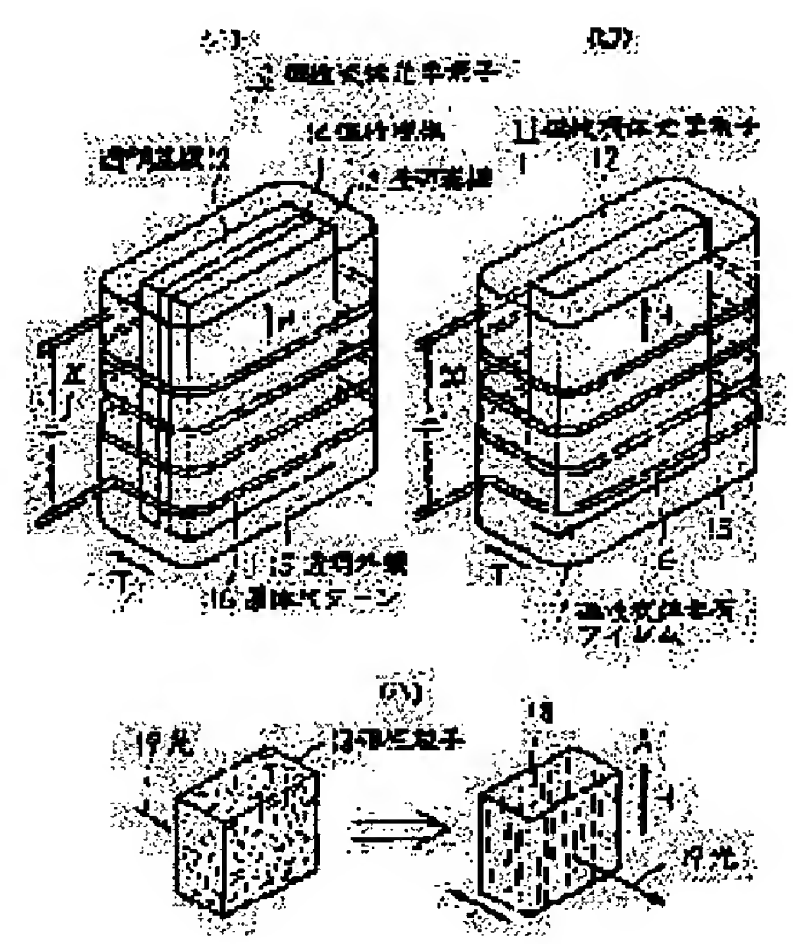
(21)Application number : 03-029766
(22)Date of filing : 25.02.1991

(71)Applicant : FUJITSU LTD
(72)Inventor : MATSUDA GENICHI

(54) MAGNETIC FLUID OPTICAL ELEMENT AND APPLYING DEVICE THEREFOR AND OPTICAL CONTROL METHOD USING MAGNETIC FLUID

(57)Abstract:
PURPOSE: To assure the contrast equal to the contrast obtd. when a liquid crystal panel is used and to miniaturize a driving power source relating to the magnetic fluid optical elements for adjusting the transmission quantity of light and the applying device thereof.



CONSTITUTION: A magnetic fluid-contg. film 17 is packaged with a transparent package 15 directly or after thin film-like magnetic fluid 14 or the magnetic fluid-contg. film 17 is held by a pair of transparent substrates 12, 13 or transparent films. Coiled transparent conductor patterns 16 in which the current to generate the orienting magnetic field H of the magnetic particles 18 of the magnetic fluid 14 or film 17 passes are provided on the transparent package 15, by which the magnetic fluid optical elements 10, 11 are constituted. Plural pieces of the magnetic fluid optical elements 10 or 11 are disposed in the form of an array or matrix, by which the applying device thereof is constituted. The current is passed to the conductor patterns 16 of the magnetic fluid optical elements 10, 11 which are alone or are combined with plural pieces, by which the transmittance thereof is regulated. A light control panel, shutter, display, etc., are thus provided.

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(51)Int.Cl. G03B 9/02
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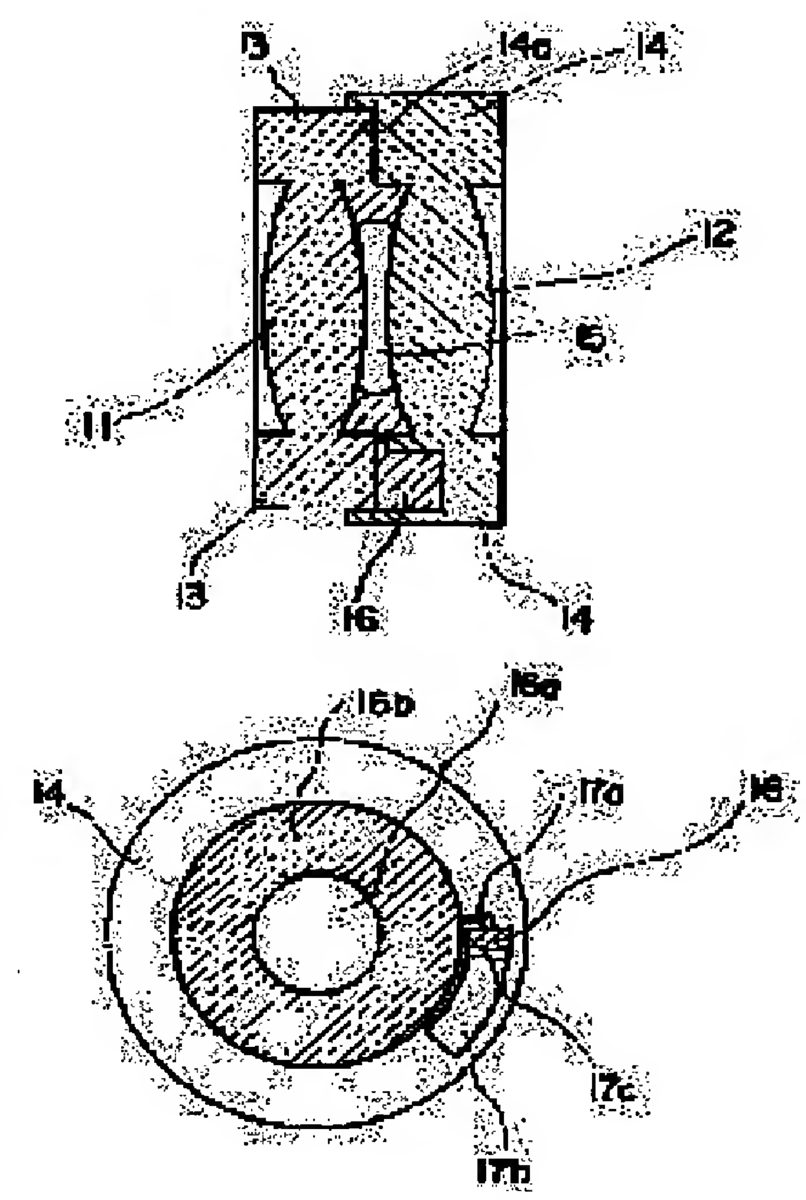
(21)Application number : 05-116156
(22)Date of filing : 18.05.1993

(71)Applicant : KONICA CORP
(72)Inventor : TAMURA TOMOAKI

(54) LIGHT QUANTITY CONTROLLER FOR CAMERA

(57)Abstract:
PURPOSE: To make a lens stop device small in size, light in weight and reduced in product cost.
CONSTITUTION: By rotating either one of lens barrels 13 with a lens member 11, a wing 17c formed on a face opposite to the lens barrel 13 is slid in a pump room 17b so as to push out light shielding fluid 16 in the pump room 17b, and then, the fluid 17 is injected into a hollow part 15. The side crosssectional shape of the hollow part 15 is formed so that the distance between lens faces facing each other become narrower as it goes from the peripheral part closer to the center, then, a part of the injected light shielding fluid 16 is moved from the peripheral part of the hollow part 15 to the central part by the surface tension of the fluid, and then, a nearly cylindrical light transmission part 16a is formed at the central part, and the light shielding part 16b filled with the light shielding fluid is formed at the peripheral part. By increasing the amount of the injected light shielding fluid 16, the area of the light shielding part 16b is enlarged and also the area of the light transmission part 16a is reduced, so that the quantity of light passing through the light transmission part 16a is controlled by changing the amount of the injected light shielding fluid 16.



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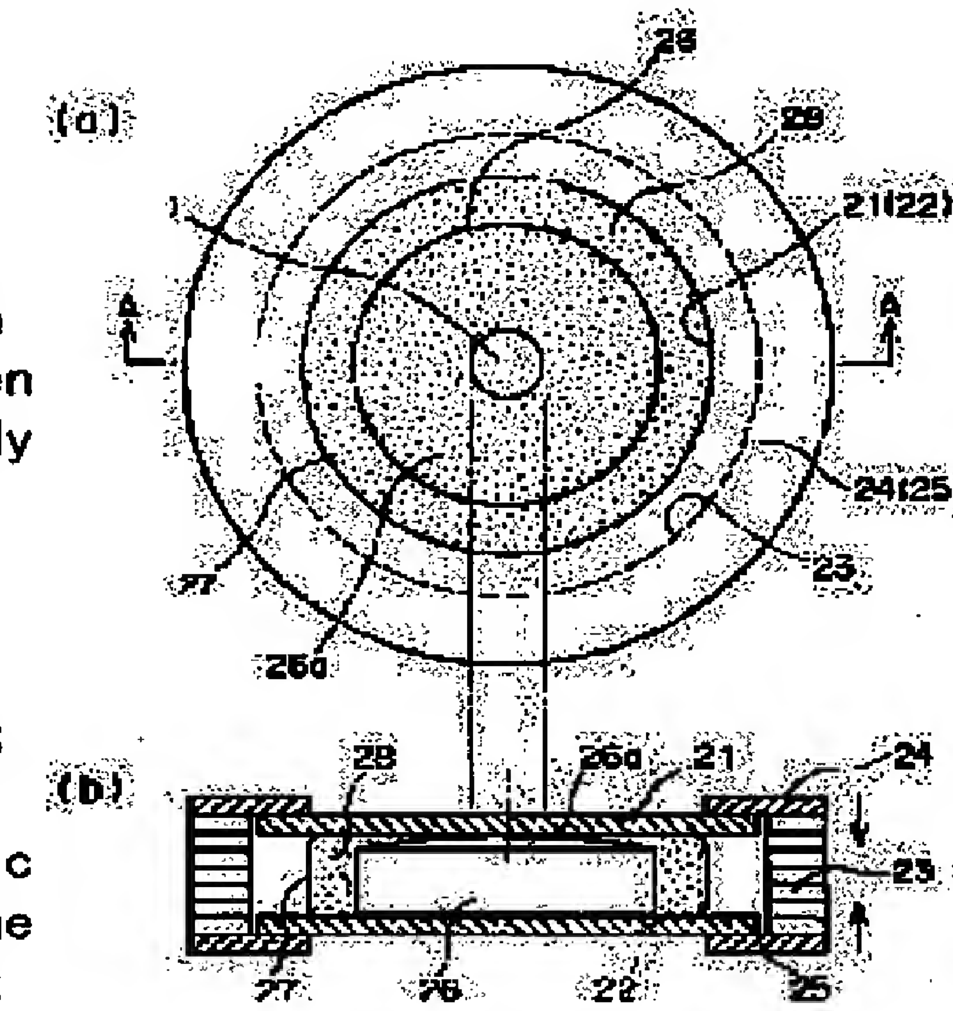
(21)Application number : 09-344601	(71)Applicant : ASAHI OPTICAL CO LTD
(22)Date of filing : 15.12.1997	(72)Inventor : SEO SHUZO

(54) IRIS DEVICE

(57)Abstract:

PROBLEM TO BE SOLVED: To provide an iris device which is capable of executing a high speed operation, while making the setting control of an aperture possible and further, reducible in size and power consumption.

SOLUTION: The iris device is provided with a pair of plane transparent plates 21 and 22 arranged to face each other in an optical axis, a piezoelectric element 23 arranged between the transparent plates 21 and 22, a transparent elastic body 26 which is attached to the inside surface of the transparent plate 22 and whose surface part 26a on a side facing the transparent plate 21 is formed in a spherical shape, an annular elastic film 27 surrounding the transparent elastic body 26 and a light shielding liquid 28 filled into the elastic film 27 and having the property of shielding light. When a voltage applied to the piezoelectric element 23 is changed and the interval between a pair of the transparent plates 21 and 22 is made small, the transparent plate 21 is brought into close contact with the spherical surface part 26a of the transparent elastic body 26, while elastically deforming it, so that the light shielding liquid 28 interposed between the transparent plate 21 and the surface part 26a is removed toward a peripheral part, light transmissivity is obtained in the close contact region and this region functions as the aperture.



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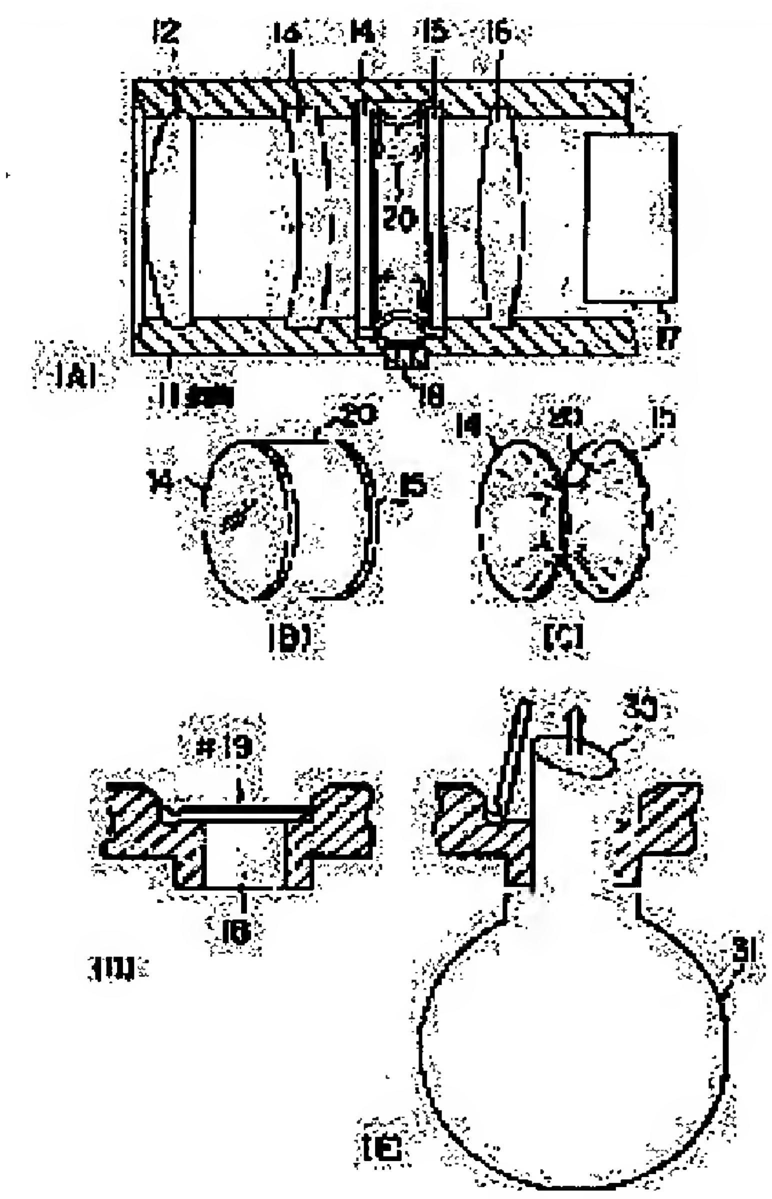
H04N 5/225

(21)Application number : 07-323011
(22)Date of filing : 12.12.1995

(71)Applicant : TOSHIBA CORP
TOSHIBA AVE CORP
(72)Inventor : YAMAUCHI HIMIO
KIMURA MASANOBU
HOSOKAWA JUNICHI

(54) DIAPHRAGM DEVICE FOR CAMERA

(57)Abstract:
PROBLEM TO BE SOLVED: To miniaturize an entire camera by providing an arranging means arranging an elastic member possessing an aperture formed to surround an optical axis at the diaphragm part of the camera and having light shielding property and an adjusting means adjusting the aperture of the elastic member by air or fluid pressure so that the diameter of the aperture may be large or small.
SOLUTION: Both ends of the elastic member 20 having the light shielding property and functioning as a diaphragm are integrated with glass plates 14 and 15 functioning as the arranging means and attached in the interior of a lens barrel 11. At such a time, both ends are fixed on the inside of the lens barrel 11. An air injection port 18 constituting the adjusting means is formed on the lens barrel 11, so that the air between the inner surface of the lens barrel 11 and the outer surface of the elastic member 20 on the periphery of both ends of the member 20 can be injected and discharged. Therefore, when the air is injected from the injection port 18, the member 20 is deformed and pushed out toward the inner periphery side of the lens barrel 11 to narrow a light introducing path. On the contrary, when the air is discharged from such a state, the member 20 is restored by the elastic force to largely open the light introducing path.



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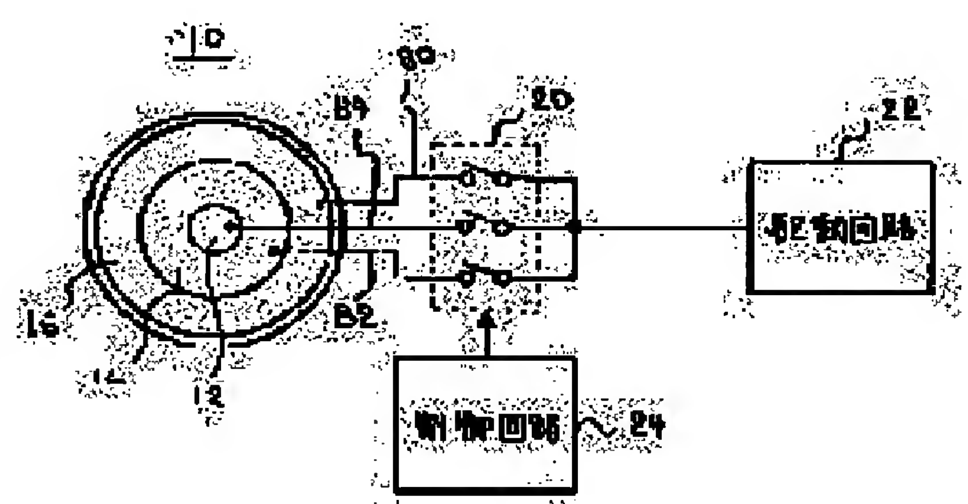
G02F 1/1333

(21)Application number : 06-028795
(22)Date of filing : 31.01.1994

(71)Applicant : SONY TEKTRONIX CORP
(72)Inventor : KOYAMA TETSUO
NABESHIMA TAKANARI

(54) ELECTRONIC DIAPHRAGM DEVICE

(57)Abstract:
PURPOSE: To enable the electronic control of a diaphragm and simultaneously the adjustment of depth of field as well by using a liquid crystal cell.
CONSTITUTION: An electronic diaphragm 10 is composed of first and second polarizing filters whose polarization angles are different or the same and the liquid crystal cell provided between these first and second filters, the liquid crystal cell is controlled by a control circuit 24 and provided with two transparent electrode body structures facing each other, a spacer and a liquid crystal material held by these two transparent electrode body structures and the spacer and the transparent conductive layer of at least one of the two transparent electrode body structures is divided into plural ones. The control circuit 24 selectively supplies a voltage for generating an electric field to the divided transparent conductive layers 12, 14 and 16.



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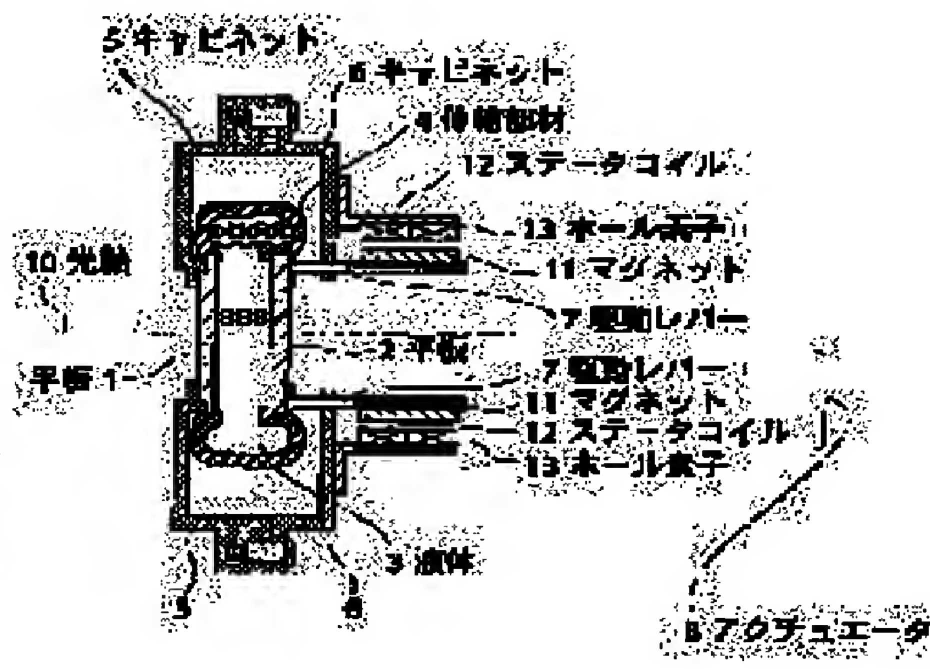
G02B 26/02

(21)Application number : 10-130387
(22)Date of filing : 13.05.1998

(71)Applicant : SONY CORP
(72)Inventor : IKEGAMI KEISUKE
MIYAGAKI EIJI

(54) OPTICAL DIAPHRAGM DEVICE

(57)Abstract:
PROBLEM TO BE SOLVED: To provide an optical diaphragm device constituted so that the effect of diffraction is reduced in the case of a minimum aperture and image quality is prevented from being deteriorated.
SOLUTION: The optical diaphragm device is constituted by including an optical diaphragm means and a detection means and a driving means arranged at the optical diaphragm means. The optical diaphragm means is constituted of two plates 1 and 2, elongation and contraction members 4 and liquid 3 with which a space surrounded by the plates 1 and 4 and the members 4 is filled. The plates 1 and 2 are constituted of a transparent or a translucent glass or plastics and installed mutually in parallel. A space between the end surface of the plate 1 and the end surface of the plate 2 is sealed by the elongation and contraction members 4. By moving the plate 2 by using the driving means, the space between the plates 1 and 2, that means, the thickness of the liquid 3 filling the space between the plates 1 and 2 is changed so as to change the optical transmissivity of the optical diaphragm means.



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Dry text

Switchable colour filter based on electro-wetting

Technical field.

In many electronic consumer devices colour filters are used. For instance, in (digital) photo and (security) cameras, a cyan colour filter is used to switch between day and night sensitivity. Another field where (switchable) colour filters are used is the one of projection systems, where the different colour images are overlaid by time sequential projection.

Technical problem.

Currently, mechanical options are used in most cases. Drawbacks of such options are that these systems are generally bulky and have a limited lifetime.

Technical measure and effect.

We propose to use electro-wetting as a method to realise a non-mechanical tuneable colour filter. The basic system and principle are illustrated in fig. 1.

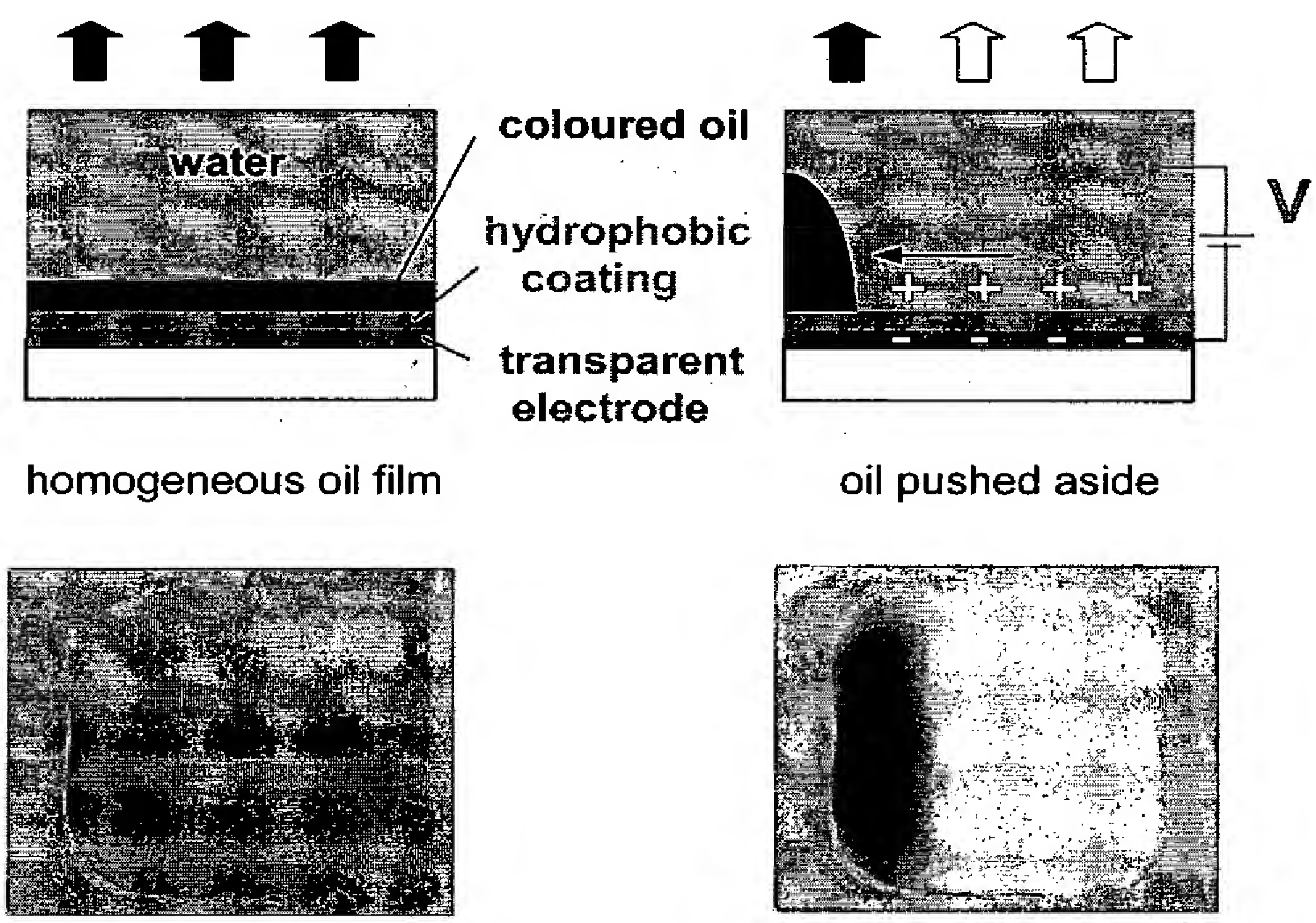

Figure 1 – *Principle of switchable colour filter based on electro-wetting (top panels). Demonstration of feasibility (lower panels). The size of the device is 5x5 mm^2.*

On the left hand side, the oil film is homogeneous and therefore active as a colour filter. On the right hand side, the oil is moved to the side and the filter becomes transparent in most of the active area. In this particular case, a white scattering substrate is placed behind the device, rendering the white colour where the oil has been removed.

An advantage of the filter is its relatively small height and the uniformity of the transmission of the filter over the cross-section of the radiation beam.

The practical demonstration in this case was achieved by using line electrodes, but other configurations are possible as well. A circularly symmetric electrode will push the oil to the side resulting in a circular transparent opening. If intermediate states, in which the size of the transparent hole is varied, are desired, several concentric ring electrodes can be used. The oil can also be collected in a corner, by having a homogeneous electrode with a small square cut in one of the corners.

A circular motion can also be achieved by initiating the motion from the centre of the device. A possibility is a small reduction of the height of the oil layer in the centre of the device, for instance by a small increase in the height of the bottom of the device. Another possibility is a slightly modification of the surface at the centre by making it locally more hydrophilic. This may be achieved by a thin protrusion from the bottom, possibly extending through the oil layer, the protrusion having a hydrophilic surface. There are several other options to steer the oil into the desired direction. One can use an insulator layer or contact layer with a varying thickness. For example, if a radially varying insulator thickness is used with the smallest thickness in the centre, the oil motion will be initiated in the centre (at the highest field) and move outward. Other thickness variations are also possible. One can also vary the interfacial tension along the walls of the filter, and thereby create a preference for the oil motion.

Using different dyes or pigments in the oil can alter the colour of the filter. The colour is not limited to the visible wavelength spectrum, but could also be active in, for instance, the UV.

In small systems (< 5mm) the surface tension is sufficiently strong to ensure stability of the device upon rotation. Larger systems can be obtained by carefully matching the density of the oil and the water.

Double non-mechanical colour filter based on electro-wetting

Technical field.

In many electronic consumer devices colour filters are used. For instance, in (digital) photo and (security) cameras, a cyan colour filter is used to switch between day and night sensitivity. Another field where (switchable) colour filters are used is the one of projection systems, where the different colour images are overlaid by time sequential projection.

Technical problem.

When multiple colour filters are needed, the known, mostly mechanical, colour filters are simply stacked. As a result, the filter stack takes up a significant amount of space.

Technical measure and effect.

We propose to create a single cell colour filter that is able to switch two colours, by using a so-called bi-layer electro-wetting cell. The basic principle of such a cell is illustrated in fig. 1.

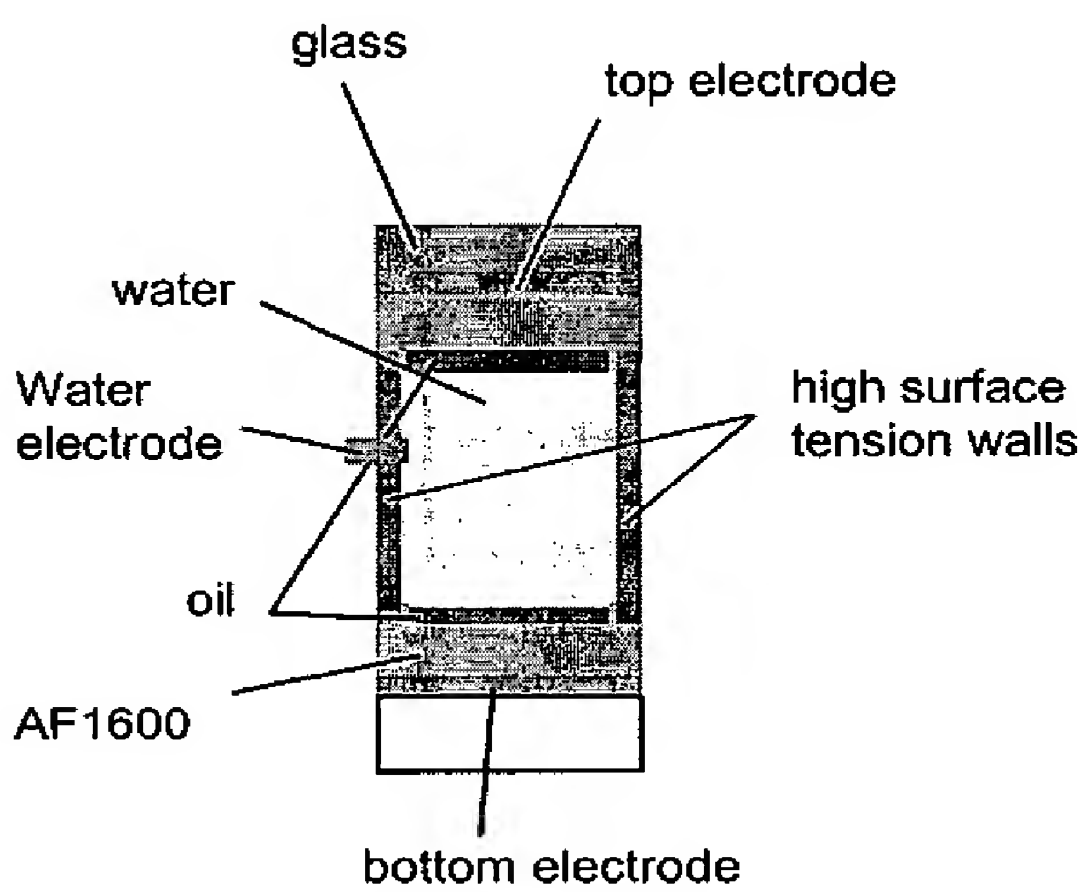

Figure 2 – *Principle of bi-layer electro-wetting colour filter. The top and bottom oil layer can be switched independently.*

In a bi-layer cell, the oil layer on top and bottom are separated physically by using walls that are hydrophilic. In such a configuration, the oil layer can be switched independently by applying a voltage to the top and/or bottom electrode, with no risk that they will mix.

When no voltage is applied the oil film is homogeneous and therefore active as a colour filter. When a voltage is applied, the oil is moved to the side and the filter becomes transparent in most of the active area.

An advantage of the filter is its relatively small height and the uniformity of the transmission of the filter over the cross-section of the radiation beam.

A practical demonstration can be seen in fig. 3 where a top view photograph of a bi-layer cell is shown. This system has an inner diameter of 5 mm and we use a cyan top layer and a magenta bottom layer. Furthermore, we used an electrode structure with 3 lines on both the top and bottom plate and the lines are perpendicularly oriented with respect to each other. In the photograph, we applied a voltage to the middle electrode, resulting in different colours at different places in the device.

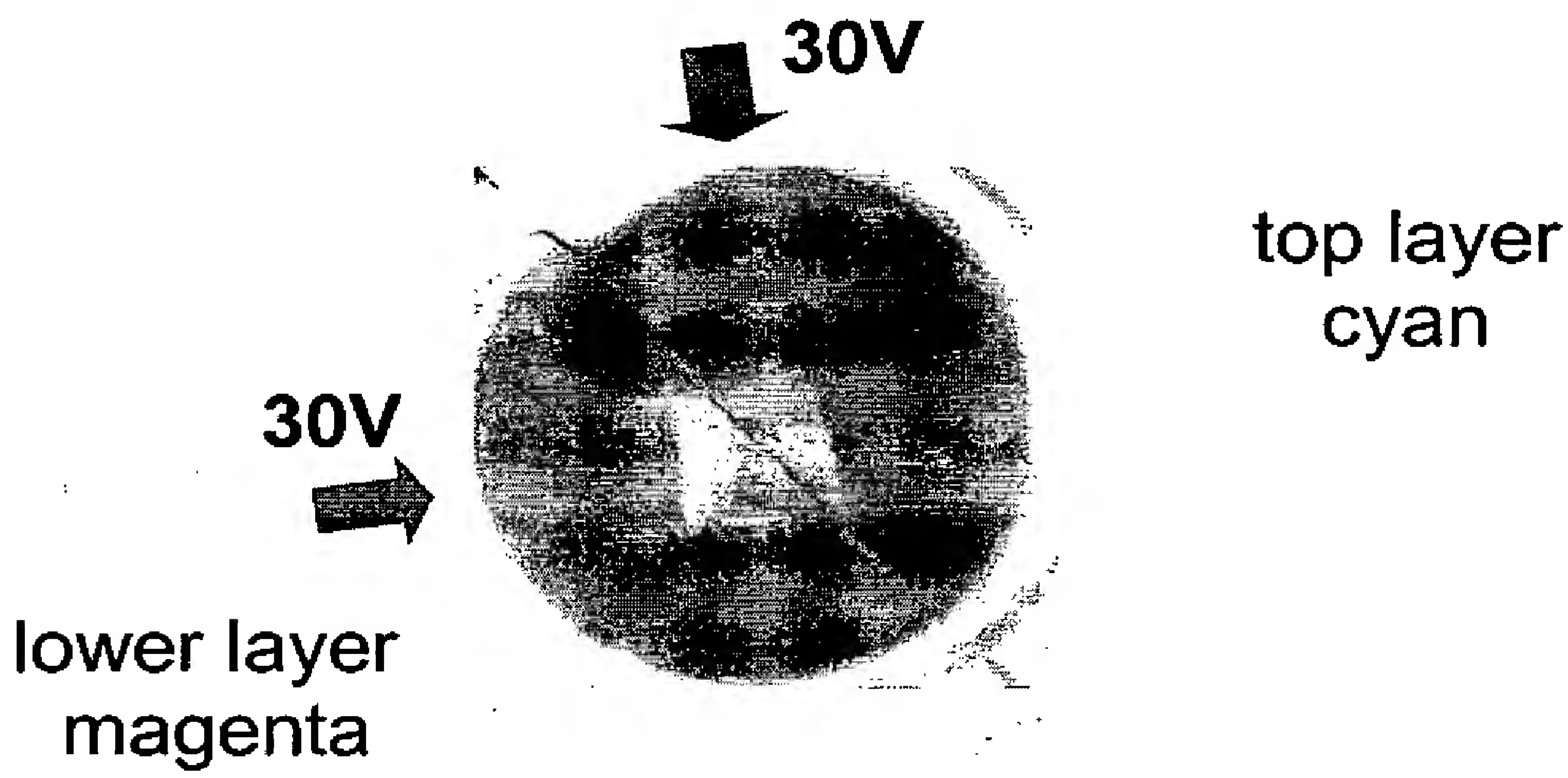

Figure 3 – *Practical demonstration of the feasibility of a bi-layer electro-wetting cell.*

Other configurations than the line electrodes are possible as well. A circularly symmetric electrode will push the oil to the side resulting in a circular transparent opening. If intermediate states, in which the size of the transparent hole is varied, are needed, several ring electrodes can be used. \

The oil can also be collected in a corner of a square device, by having a homogeneous electrode with a small square cut in one of the corners.

A circular motion can also be achieved by initiating the motion from the centre of the device, for instance by slightly modifying the surface at the centre (making it locally more hydrophilic). There are several other options to steer the oil into the desired direction. One can use an insulator layer with a varying thickness. For example, if a radially varying insulator thickness is used with the smallest thickness in the centre, the oil motion will be initiated in the centre (at the highest field) and move outward. Other thickness variations are also possible. One can also vary the interfacial tension along the walls of the filter, and thereby create a preference for the oil motion.

Using different additives such as dyes or pigments in the oil one can alter the transmittance of the filter. When the transmittance has a non-uniform spectral distribution, the filter may be used as a colour filter. The transmittance change is not limited to the visible wavelength spectrum, but could also be active in, for instance, the UV.

In small systems (< 5mm) the surface tension is sufficiently strong to ensure stability of the device upon rotation. Larger systems can be made stable by matching the density of the oil and the water.

Claims

1 A switchable optical filter comprising a fluid chamber having an optical axis and including a first fluid and an axially displaced second fluid, the fluids being non-miscible, in contact along a first meniscus and having different transmissivities, the fluid chamber also including a first electrode in contact with the first fluid and a second electrode separated from the second fluid by a first contact layer, wherein the position of the second fluid is movable in a direction away from the optical axis by application of a voltage over the first and second electrodes, thereby changing the transmissivity of the fluid chamber in a direction along the optical axis.

2 The optical filter according to Claim 1, wherein the first contact layer is hydrophobic.

3 The optical filter according to Claim 1, wherein the second electrode is transparent and arranged in a plane perpendicular to the optical axis.

4 The optical filter according to Claim 1, wherein the first fluid is water and the second fluid is an oil.

5 The optical filter according to Claim 1, wherein the second fluid comprises an additive changing the transmissivity of the second fluid.

6 The optical filter according to Claim 1, wherein the specific mass of the first and second fluid are substantially equal.

7 The optical filter according to Claim 1, wherein the second electrode generates a increased field in the centre of the chamber.

8 The optical filter according to Claim 1, wherein the thickness of the first contact layer is non-uniform.

9 The optical filter according to Claim 1, wherein the thickness of the second fluid on the optical axis at zero applied voltage is smaller than the thickness around the optical axis.

10 The optical filter according to Claim 1, wherein the fluid chamber includes a third fluid axially displaced with respect to the first and second fluid, the first and third fluid being non-miscible, in contact along a second meniscus and having different transmissivities, the fluid chamber also including a third electrode separated from the third fluid by a second contact layer, wherein the position of the third fluid is movable in a direction perpendicular to the optical axis by application of a voltage over the first and third electrodes, thereby changing the transmissivity of the fluid chamber in a direction along the optical axis.

11 The optical filter according to Claim 10, wherein the second contact layer is hydrophobic.

12 The optical filter according to Claim 10, wherein the third electrode is transparent and arranged in a plane perpendicular to the optical axis.

13 The optical filter according to Claim 10, wherein the third fluid is an oil.

14 The optical filter according to Claim 13, wherein the second and third fluid have different spectral distributions of the transmissivity.

15 The optical filter according to Claim 10, wherein the specific mass of the first and third fluid are substantially equal.

Variable Focus Lens

This invention relates to a variable focus lens comprising a first fluid and a second fluid which are in contact over a meniscus and to a method of operating such a variable focus lens. The shape of the meniscus can be controlled by a voltage.

A fluid is a substance that alters its shape in response to any force, that tends to flow or to conform to the outline of its chamber, and that includes gases, liquids and mixtures of solids and liquids capable of flow.

The meniscus between the first fluid and the second fluid is called concave, if the meniscus is hollow as seen from the second fluid. If the first fluid is regarded as a lens, this lens would normally called concave if the meniscus is concave according to the definition in the previous sentence.

A variable focus lens having such an arrangement is described in International patent application WO 99/18456. In this arrangement, the lens comprises a chamber filled with a conductive first liquid, a droplet of an insulating, non-miscible second liquid being held in a surface zone of the chamber wall by a fluid contact layer applied on the wall. The fluid contact layer positions the droplet because part of the fluid contact layer is hydrophobic and an adjacent part is hydrophilic. Application of a voltage to electrodes in the chamber causes the refracting upper surface or meniscus of the droplet to become more convex. In one embodiment, the hydrophobic and hydrophilic parts of the fluid contact layer are arranged along a cylindrical surface, the sides of the droplet being positioned axially along the cylindrical surface, and thereby centred, by the hydrophilic part when no voltage is applied and by a series of electrodes along the sides of the cylinder when a voltage is applied. Such a lens is complex to manufacture and, particularly in the cylindrical configuration, requires a relatively high voltage in order to alter the lens characteristics of the droplet, which can cause premature degradation of the lens when used over a period of time.

A further variable focus lens having such an arrangement is described in the international patent application WO 00/58763. The proposed means for centring a droplet of insulating liquid is a bell-mouthed recess formed of an insulating layer in an adjustable lens. The sides of the recess are arranged so as to keep the droplet centred within the recess and to provide a convex refracting surface on the droplet. The recess is shaped such that the

manufacture of such a lens remains relatively complex, and since the base of the recess is formed of the same material as the sides of the recess, such material must be chosen to be transparent if the lens is to be operative.

In accordance with the present invention, there is provided a variable focus lens including

a substantially cylindrical fluid chamber having a cylinder wall and an axis, the fluid chamber including a first fluid (A) and an axially displaced second fluid (B), the fluids being non-miscible, in contact over a meniscus and having different indices of refraction,

a fluid contact layer arranged on the inside of the cylinder wall,

a first electrode separated from the first fluid and second fluid by the fluid contact layer,

a second electrode acting on the second fluid,

the fluid contact layer having a wettability by the second fluid which varies under the application of a voltage between the first electrode and the second electrode, such that the shape of the meniscus varies in dependence on the said voltage,

wherein the wettability of the fluid contact layer by the second fluid is substantially equal on both sides of the intersection of the meniscus with the contact layer when no voltage is applied between the first and second electrodes.

The equal wettability of the fluid contact layer on both sides of the intersection allows a larger movement of the meniscus and, as a consequence, a greater change in curvature of the meniscus. It allows a concave meniscus to become convex or vice versa.

In a preferred embodiment the lens is arranged to produce a meniscus shape which is concave, the shape becoming less concave at increasing magnitude of voltage applied between the first and second electrodes. With the fluid contact layer substantially cylindrical, the tendency of the first fluid to wet the fluid contact surface can be used to produce the concave meniscus shape, and furthermore, relatively low voltages can be used to vary the meniscus shape to alter the power of the lens. Thereby, a desired range in lens power may be produced without the application of excess voltage.

By using a substantially cylindrical inner surface of the fluid contact layer and arranging the lens to produce a concave meniscus shape, the range in lens power of the lens can be improved without the application of excess voltage. At sufficiently high magnitude of voltage the shape of the meniscus may become convex. Application of excess voltage can

lead to the charging of the fluid contact layer, which has been found to cause degradation of the layer, leading to a significant reduction in the useful lifetime of the lens.

A substantially cylindrical inner surface for the fluid contact layer may be produced without the need for complex processing techniques. In particular, such an inner surface shape may be produced by dip coating of a cylindrical electrode, which is a relatively reliable and inexpensive procedure. The fluid contact layer is furthermore preferably of a uniform thickness so as to provide a reliable refractive behaviour of the meniscus throughout the adjustable range of the lens. Again, such a uniform fluid contact layer can be readily produced by dip coating a cylindrical electrode element.

A second aspect of the invention relates to a method of operating a variable focus lens including a substantially cylindrical fluid chamber having a cylinder wall, the fluid chamber including a first fluid (A) and an axially displaced second fluid (B), the fluids being non-miscible, in contact over a meniscus and having different indices of refraction, a fluid contact layer arranged on the inside of the cylinder wall, a first electrode separated from the first fluid and second fluid by the fluid contact layer, a second electrode acting on the second fluid, the wettability of the fluid contact layer by the second fluid being substantially equal on both sides of the intersection of the meniscus with the contact layer when no voltage is applied between the first and second electrodes, the wettability of the fluid contact layer by the second fluid varying under the application of a voltage between the first electrode and the second electrode, the method comprising controlling the said voltage to change the shape of the meniscus.

Further features and advantages of the invention will become apparent from the following description of preferred embodiments of the invention, wherein:

Figures 1 to 3 show an adjustable lens in accordance with an embodiment of the invention in schematic cross section;

Figure 4 shows an image capture device in accordance with an embodiment of the invention in schematic cross section; and

Figure 5 shows an optical scanning device in accordance with an embodiment of the invention in schematic cross section.

Figures 1 to 3 show a variable focus lens comprising a cylindrical first electrode 2 forming a capillary tube, sealed by means of a transparent front element 4 and a

transparent back element 6 to form a fluid chamber 5 containing two fluids. The electrode 2 may be a conducting coating applied on the inner wall of a tube.

In this embodiment the two fluids consist of two non-miscible liquids in the form of an electrically insulating first liquid A, such as a silicone oil or an alkane, referred to herein further as "the oil", and an electrically conducting second liquid B, such as water containing a salt solution. The two liquids are preferably arranged to have an equal density, so that the lens functions independently of orientation, i.e. without dependence on gravitational effects between the two liquids. This may be achieved by appropriate selection of the first liquid constituent; for example alkanes or silicon oils may be modified by addition of molecular constituents to increase their density to match that of the salt solution.

Depending on the choice of the oil used, the refractive index of the oil may vary between 1.25 and 1.60. Likewise, depending on the amount of salt added, the salt solution may vary in refractive index between 1.33 and 1.48. The fluids in this embodiment are selected such that the first fluid A has a higher refractive index than the second fluid B.

The first electrode 2 is a cylinder of inner radius typically between 1 mm and 20 mm. The electrode 2 is formed from a metallic material and is coated by an insulating layer 8, formed for example of parylene. The insulating layer has a thickness of between 50 nm and 100 μm, with typical values between 1 μm and 10 μm. The insulating layer is coated with a fluid contact layer 10, which reduces the hysteresis in the contact angle of the meniscus with the cylindrical wall of the fluid chamber. The fluid contact layer is preferably formed from an amorphous fluorocarbon such as Teflon™ AF1600 produced by DuPont™. The fluid contact layer 10 has a thickness of between 5 nm and 50 μm. The AF1600 coating may be produced by successive dip coating of the electrode 2, which forms a homogeneous layer of material of substantially uniform thickness since the cylindrical sides of the electrode are substantially parallel to the cylindrical electrode; dip coating is performed by dipping the electrode whilst moving the electrode in and out of the dipping solution along its axial direction. The paralyne coating may be applied using chemical vapour deposition. The wettability of the fluid contact layer by the second fluid is substantially equal on both sides of the intersection of the meniscus 14 with the fluid contact layer 10 when no voltage is applied between the first and second electrodes.

A second, annular electrode 12 is arranged at one end of the fluid chamber, in this case, adjacent the back element. The second electrode 12 is arranged with at least one part in the fluid chamber such that the electrode acts on the second fluid B.

The two fluids A and B are non-miscible so as to tend to separate into two fluid bodies separated by a meniscus 14. When no voltage is applied between the first and second electrodes, the fluid contact layer has a higher wettability with respect to the first fluid A than the second fluid B. Due to electrowetting, the wettability by the second fluid B varies under the application of a voltage between the first electrode and the second electrode, which tends to change the contact angle of the meniscus at the three phase line (the line of contact between the fluid contact layer 10 and the two liquids A and B). The shape of the meniscus is thus variable in dependence on the applied voltage.

Referring now to Figure 1, when a low voltage V_1, e.g. between 0 V and 20 V, is applied between the electrodes the meniscus adopts a first concave meniscus shape. In this configuration, the initial contact angle θ_1 between the meniscus and the fluid contact layer 10, measured in the fluid B, is for example approximately 140°. Due to the higher refractive index of the first fluid A than the second fluid B, the lens formed by the meniscus, here called meniscus lens, has a relatively high negative power in this configuration.

To reduce the concavity of the meniscus shape, a higher magnitude of voltage is applied between the first and second electrodes. Referring now to Figure 2, when an intermediate voltage V_2, e.g. between 20 V and 150 V, depending on the thickness of the insulating layer, is applied between the electrodes the meniscus adopts a second concave meniscus shape having a radius of curvature increased in comparison with the meniscus in Figure 1. In this configuration, the intermediate contact angle θ_2 between the first fluid A and the fluid contact layer 10 is for example approximately 100°. Due to the higher refractive index of the first fluid A than the second fluid B, the meniscus lens in this configuration has a relatively low negative power

To produce a convex meniscus shape, a yet higher magnitude of voltage is applied between the first and second electrodes. Referring now to Figure 3, when a relatively high voltage V_3 , e.g. 150 V to 200 V, is applied between the electrodes the meniscus adopts a meniscus shape in which the meniscus is convex. In this configuration, the maximum contact angle θ_3 between the first fluid A and the fluid contact layer 10 is for example approximately 60°. Due to the higher refractive index of the first fluid A than the second fluid B, the meniscus lens in this configuration has a positive power.

Note that, whilst achieving the configuration of Figure 3 is possible using a relatively high power, it is preferred in a practical embodiment that a device including the lens as described is adapted to use only low and intermediate powers in the ranges described, that is to say that the voltage applied is restricted such that the electrical field strength in the

insulating layer is smaller than 20 V/μm, and excessive voltages causing charging of the fluid contact layer, and hence degradation of the fluid contact layer, are not used.

Note furthermore that the initial, low voltage, configuration will vary in dependence on the selection of the liquids A and B, in dependence on their surface tensions). By selecting an oil with a higher surface tension, and/or by adding a component, such as ethylene glycol, to the salt solution which reduces its surface tension, the initial contact angle can be decreased; in this case the lens may adopt a low optical power configuration corresponding to that shown in Figure 2, and an intermediate power configuration corresponding to that shown in Figure 3. In any case, the low power configuration remains such that the meniscus is concave, and a relatively wide range of lens powers can be produced without using an excessive voltage.

Although the fluid A has a higher refractive index than fluid B in the above example, the fluid A may also have a lower refractive index than fluid B. For example, the fluid A may be a (per)fluorinated oil, which has a lower refractive index than water. In this case the amorphous fluoropolymer layer is preferably not used, because it might dissolve in fluorinated oils. An alternative fluid contact layer is e.g. a paraffin coating.

Figure 4 illustrates a variable focus image capture device including a lens in accordance with an embodiment of the present invention. Elements similar to that described in relation to Figures 1 to 3 are provided with the same reference numerals, incremented by 100, and the previous description of these similar elements should be taken to apply here.

The device includes a compound variable focus lens including a cylindrical first electrode 102, a rigid front lens 104 and a rigid rear lens 106. The space enclosed by the two lenses and the first electrode forms a cylindrical fluid chamber 105. The fluid chamber holds the first and second fluids A and B. The two fluids touch along a meniscus 114. The meniscus forms a meniscus lens of variable power, as previously described, depending on a voltage applied between the first electrode 102 and the second electrode 112. In an alternative embodiment, the two fluids A and B have changed position.

The front lens 104 is a convex-convex lens of highly refracting plastic, such as polycarbonate or cyclic olefin copolymer, and having a positive power. At least one of the surfaces of the front lens is aspherical, to provide desired initial focusing characteristics. The rear lens element 106 is formed of a low dispersive plastic, such as COC (cyclic olefin copolymer) and includes an aspherical lens surface which acts as a field flattener. The other surface of the rear lens element may be flat, spherical or aspherical. The second electrode 112

is an annular electrode located to the periphery of the refracting surface of the rear lens element 106.

A glare stop 116 and an aperture stop 118 are added to the front of the lens. A pixellated image sensor 120, such as a CMOS sensor array, is located in a sensor plane behind the lens.

An electronic control circuit 122 drives the meniscus lens, in accordance with a focus control signal, derived by focus control processing of the image signals, so as to provide an object range of between infinity and 10 cm. The control circuit controls the applied voltage between a low voltage level, at which focusing on infinity is achieved, and higher voltage levels, when closer objects are to be focused. When focusing on infinity, a concave meniscus with a contact angle of approximately 140° is produced, whilst when focusing on 10 cm, a concave meniscus with a contact angle of approximately 100° is produced.

The conducting second fluid, the insulating layer and the second electrode form an electrical capacitor, the capacitance of which depends on the position of the meniscus. The capacitance can be measured using a conventional capacitance meter. The optical strength of the meniscus lens can be determined from the measured value of the capacitance.

The lens is configured such that a low, non-zero, voltage is applied to focus the lens on an object at infinity (parallel incoming rays), so as to provide the capability to focus on infinity within reasonable manufacturing tolerances; if on the other hand the lens were to be configured such that focusing on infinity occurred when zero voltage is applied, more strict manufacturing tolerances would have to be applied.

The front lens element 104 is preferably formed as a single body with a tube holding the electrode 102 on its inner surface and closed off by the rear lens 106 to form a sealed unit. The second lens element 106 may be extended, in relation to that shown in Figure 4, and the flat rear surface of the lens element 106 may be replaced by an angled mirror surface, preferably angled at 45°, to allow the image sensor 120 to be placed below the lens, in order to reduce the dimensions of the lens.

The fluid chamber 105 may be provided with an expansion chamber to accommodate volume changes due to thermal expansion of the fluids. The expansion chamber may be a flexible membrane in one of the walls of the fluid chamber.

The inner surfaces of the front lens 104 and the rear lens 106 may be coated with a protective layer to avoid incompatibility of the material from which the lenses are

made with the fluids A and B. The protective layer may also have anti-reflection characteristics.

Figure 5 shows elements from an optical scanning device containing a lens in accordance with an embodiment of the invention. The device is for recording and/or playback from an optical disk 206, for example a dual layer digital video recording (DVR) disk (see for instance the article by K. Schep, B.Stek, R. van Woudenberg, M. Blum, S. Kobayashi, T. Narahara, T. Yamagami, H.Ogawa, "Format description and evaluation of the 22.5 GB DVR disc", Technical Digest, ISOM 2000, Chitose, Japan, Sept. 5-8, 2000). The device includes a compound objective lens, for instance having a numerical aperture of 0.85, including a rigid front lens 202 and a rigid rear lens 204, for instance as described in International patent application WO 01/73775, for focusing the incoming collimated beam, for instance having a wavelength of 405 nm, consisting of substantially parallel rays, to a spot 208 in the plane of an information layer currently being scanned.

In dual layer DVR disks the two information layers are at depths of 0.1 mm and 0.08 mm; they are thus separated by typically 0.02 mm. When refocusing from one layer to the other, due to the difference in information layer depth, some 200 mλ of unwanted spherical wavefront aberration arises, which needs to be compensated. One way to achieve this is to change the vergence of the incoming beam using a mechanical actuator, for example moving a collimator lens in the device, which is relatively expensive. Another approach is to use a switchable liquid crystal cell, which is also a relatively expensive solution.

In this embodiment, a switchable variable focus lens 200 similar to that described in relation to Figures 1 to 3 is used. In this embodiment, the oil chosen is polydimethyl (8-12%)-phenylmethylsiloxane copolymer, and a salt water solution is used as the conducting liquid. Each of the liquids, when the lens 200 is arranged with a planar meniscus, has a thickness of approximately 1 mm.

The device includes an electronic control circuit 222 for applying one of two selected voltages to the electrodes of the lens 200 in dependence on the information layer currently being scanned. In one configuration, during the scanning of the information layer depth of 0.08mm, a relatively low selected voltage is applied to produce a meniscus curvature of radius R=-21.26mm. In the other configuration, during the scanning of the information layer depth of 0.1mm, a relatively high selected voltage is applied to produce a planar meniscus curvature. As a result, the root mean square value of the wavefront aberration can be reduced from 200 mλ to 18 mλ. Note that a similar effect can be obtained using different combinations of meniscus curvatures, since only a variation in lens power is required;

furthermore the difference in lens power can also be achieved with larger movements in the meniscus by making the refractive indices of the two liquids more similar.

Note, in relation to all the above embodiments, the electrode is itself preferably cylindrical, but some variation from a perfect cylinder is possible, e.g. slightly conical. However, the cylinder should preferably remain substantially cylindrical, namely where the fluid contact layer has a linear cross section, i.e. the layer forms straight lines in a cross section of the cylinder, where the axis of the cylinder lies in the cross section. The linear cross section should be parallel to the axis of the electrode at least to within 10 degrees, more preferably at least to within 1 degree. A cylindrical electrode can be made using conventional, cheap tubing having a cross section which is parallel to the axis within 0.1 degree and a smooth inner wall on which the various layers can be deposited. The possibility to use such tubing gives the lens according to the invention a cost advantage. The fluid contact layer may itself not be perfectly linear; however any non-linearity is preferably limited such that the non linearity causes a difference in radial extent less than one tenth, more preferably less than one twentieth, of the axial extent of the electrode.

The above embodiments are to be understood as illustrative examples of the invention. Further embodiments of the invention are envisaged. For example, the first fluid may consist of a vapour rather than an insulating liquid. The second fluid may be a fluid having a lower surface tension than the first fluid. In that case the shape of the meniscus at low applied voltages will be convex.

It is to be understood that any feature described in relation to one embodiment may also be used in other of the embodiments.

Furthermore, equivalents and modifications not described above may also be employed without departing from the scope of the invention, which is defined in the accompanying claims.

CLAIMS:

1. A variable focus lens including
a substantially cylindrical fluid chamber having a cylinder wall, the fluid chamber including a first fluid (A) and an axially displaced second fluid (B), the fluids being non-miscible, in contact over a meniscus (14) and having different indices of refraction,
a fluid contact layer (10) arranged on the inside of the cylinder wall,
a first electrode (2) separated from the first fluid and second fluid by the fluid contact layer,
a second electrode (12) acting on the second fluid,
the fluid contact layer having a wettability by the second fluid which varies under the application of a voltage between the first electrode and the second electrode, such that the shape of the meniscus varies in dependence on the said voltage,
wherein the wettability of the fluid contact layer by the second fluid is substantially equal on both sides of the intersection of the meniscus with the contact layer when no voltage is applied between the first and second electrodes.

2. A lens according to claim 1, wherein the inner surface of the fluid contact layer has a linear cross-section, and wherein the linear cross section is parallel to the axis of the substantially cylindrical shape of the surface to within 10 degrees.

3. A lens according to claim 1, wherein the first fluid includes an insulating liquid and the second fluid includes a conducting liquid.

4. A lens according to claim 1, wherein the first fluid includes a vapour and the second fluid includes a conducting liquid.

5. A lens according to any one of the preceding claims, wherein the lens is arranged to produce a meniscus shape which is concave when viewed from the second fluid, the shape becoming less concave at increasing magnitude of voltage applied between the first and second electrodes.

6. A lens according to any preceding claim, wherein the fluid contact layer is a substantially homogeneous layer of uniform thickness.

7. A lens according to any preceding claim, wherein said first electrode is substantially cylindrical.

8. A lens according to any preceding claim, wherein said first fluid has a larger refractive index than said second fluid and wherein the lens is a compound lens comprising at least one fixed lens element (104) providing a positive lens power, such that the compound lens has a positive lens power when the meniscus is convex in relation to the first fluid.

9. An optical device comprising a lens according to any preceding claim, the device comprising means defining a focusing plane (120) wherein the lens is arranged such that when radiation consisting of parallel rays is input and a non-zero voltage is applied between the first and second electrodes, the radiation is focused on the focusing plane.

10. An image capture device comprising a lens according to any preceding claim.

11. An optical scanning device for scanning an optical record carrier, comprising a lens according to any of claims 1 to 10.

12. An optical scanning device according to claim 12, wherein said lens is arranged to correct for spherical aberrations arising during the scanning of different information layer depths in optical record carriers being scanned.

13. A method of operating a variable focus lens including a substantially cylindrical fluid chamber having a cylinder wall, the fluid chamber including a first fluid (A) and an axially displaced second fluid (B), the fluids being non-miscible, in contact over a meniscus (14) and having different indices of refraction,
a fluid contact layer (10) arranged on the inside of the cylinder wall,
a first electrode (2) separated from the first fluid and second fluid by the fluid contact layer,
a second electrode (12) acting on the second fluid,

the wettability of the fluid contact layer by the second fluid being substantially equal on both sides of the intersection of the meniscus with the contact layer when no voltage is applied between the first and second electrodes,

the wettability of the fluid contact layer by the second fluid varying under the application of a voltage between the first electrode and the second electrode,

the method comprising controlling the said voltage to change the shape of the meniscus.

14. A method according to claim 13 wherein said method comprises varying said voltage to produce a meniscus shape which is concave when viewed from the second fluid.

15. A method according to claim 13 or 14, wherein said method further comprises varying said voltage to produce a meniscus shape which is convex when viewed from second fluid.

16. A method according to claim 15, wherein said meniscus has a contact angle with the fluid contact layer of between 100 and 140 degrees.

ABSTRACT:

A variable focus lens comprising a first fluid (A) and a second, non-miscible, fluid (B) in contact over a meniscus. A first electrode (2) separated from the fluid bodies by a fluid contact layer (10), and a second electrode (12) in contact with the first fluid to cause an electrowetting effect whereby the shape of the meniscus is altered. The fluid contact layer has a substantially cylindrical inner wall.

Figure 1

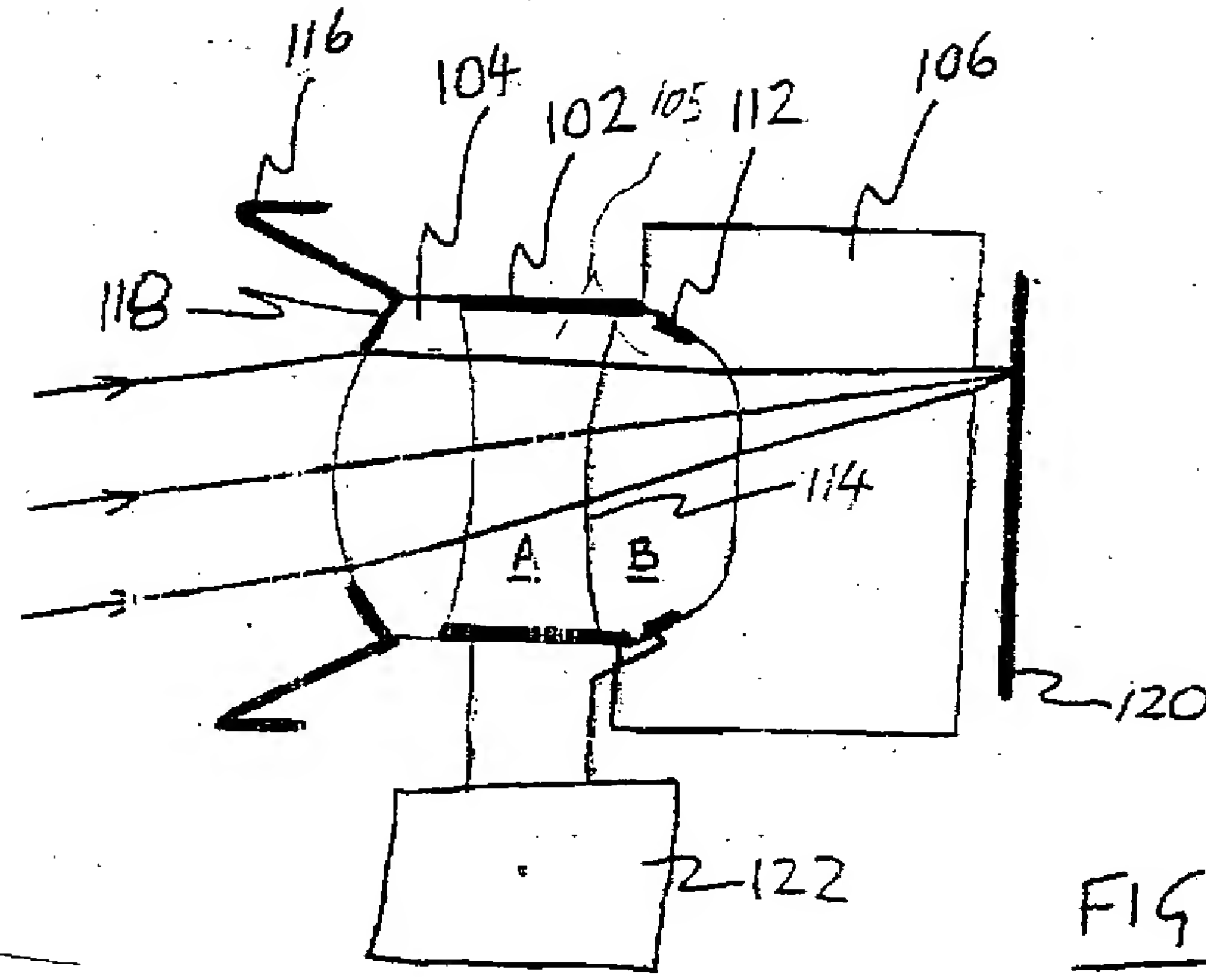
116
104
102
105
112
106
118
114
A
B
120
122

FIG. 4

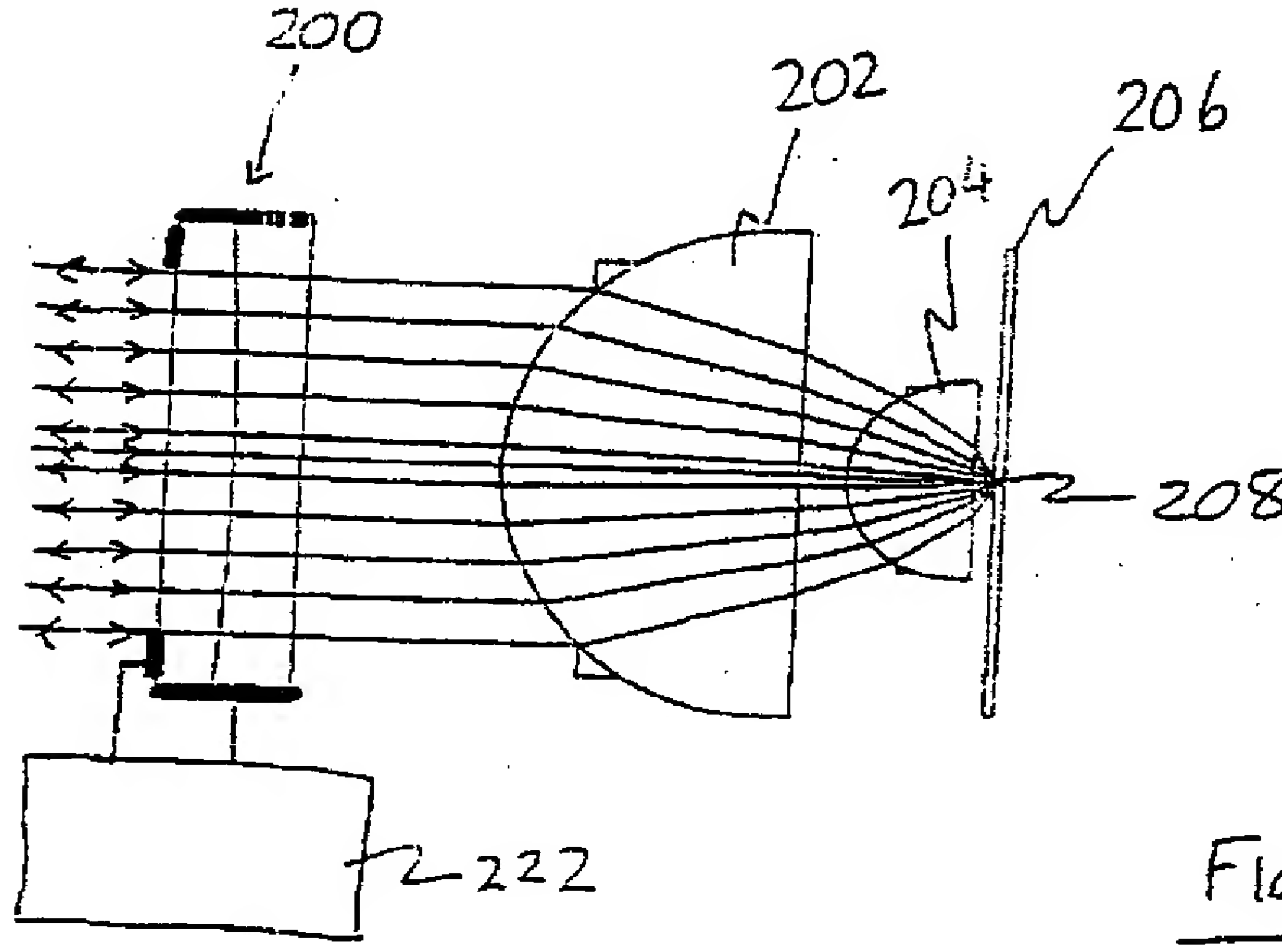
200
202
206
204
208
222

FIG. 5

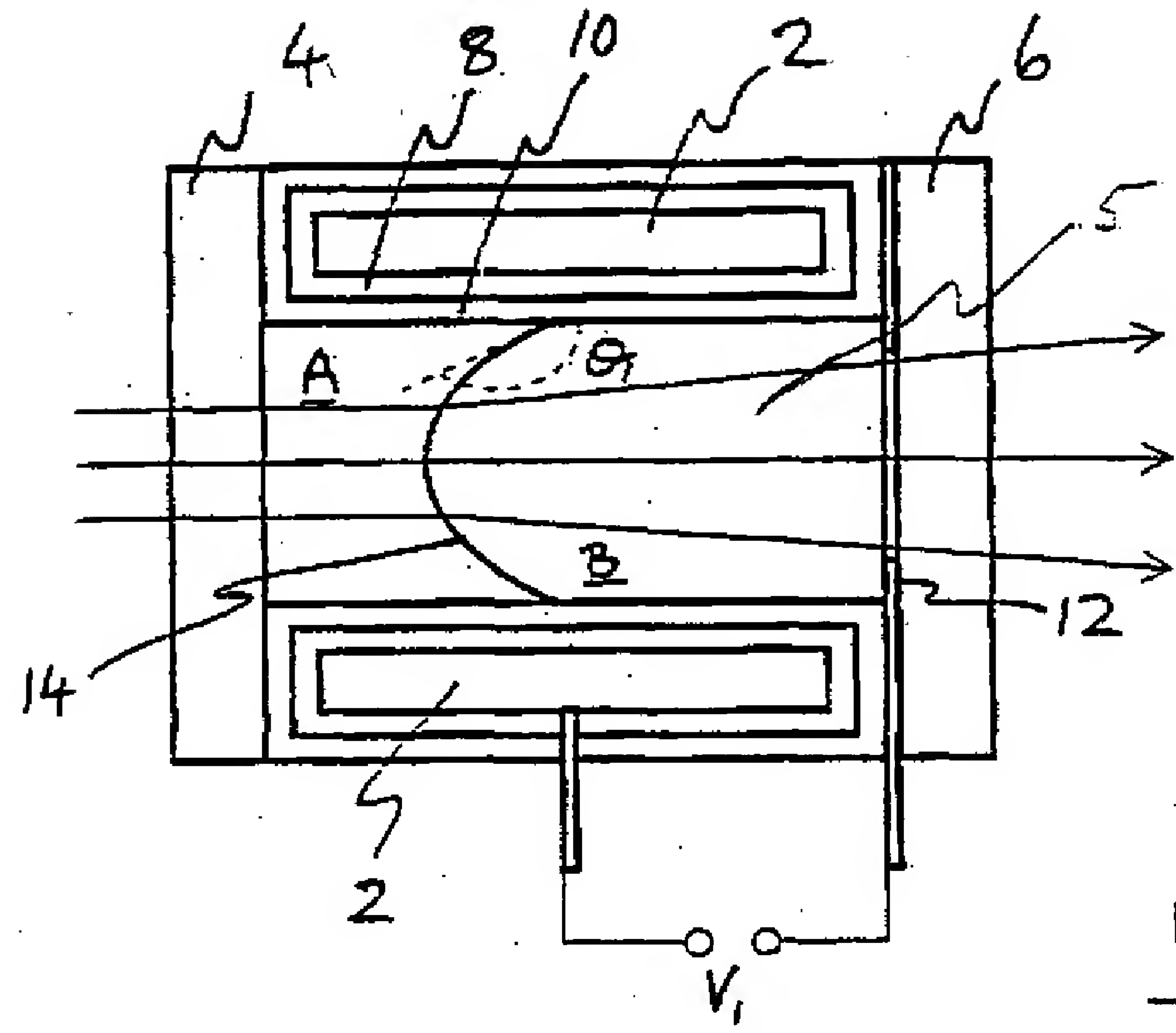

FIG.1

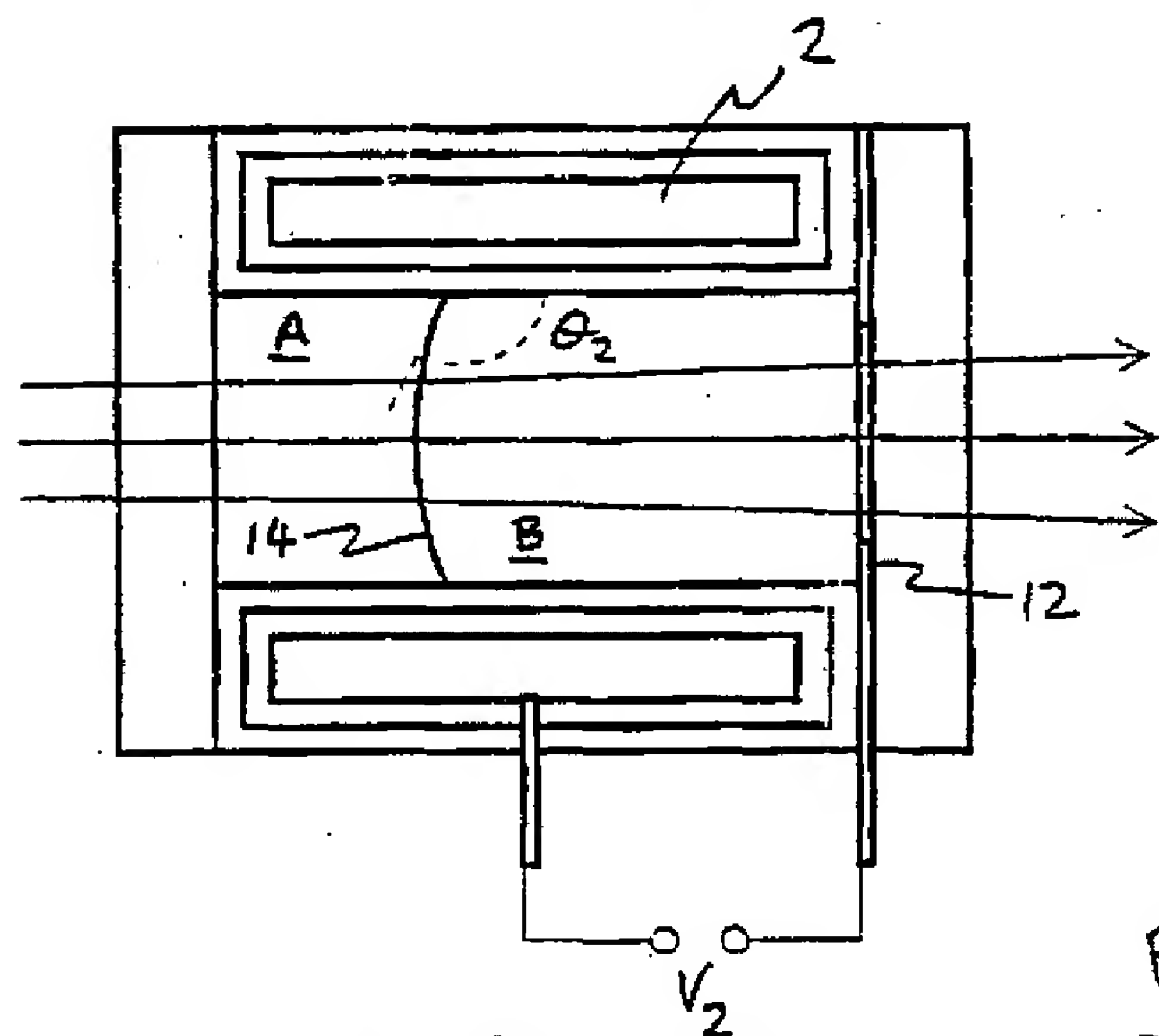

FIG.2

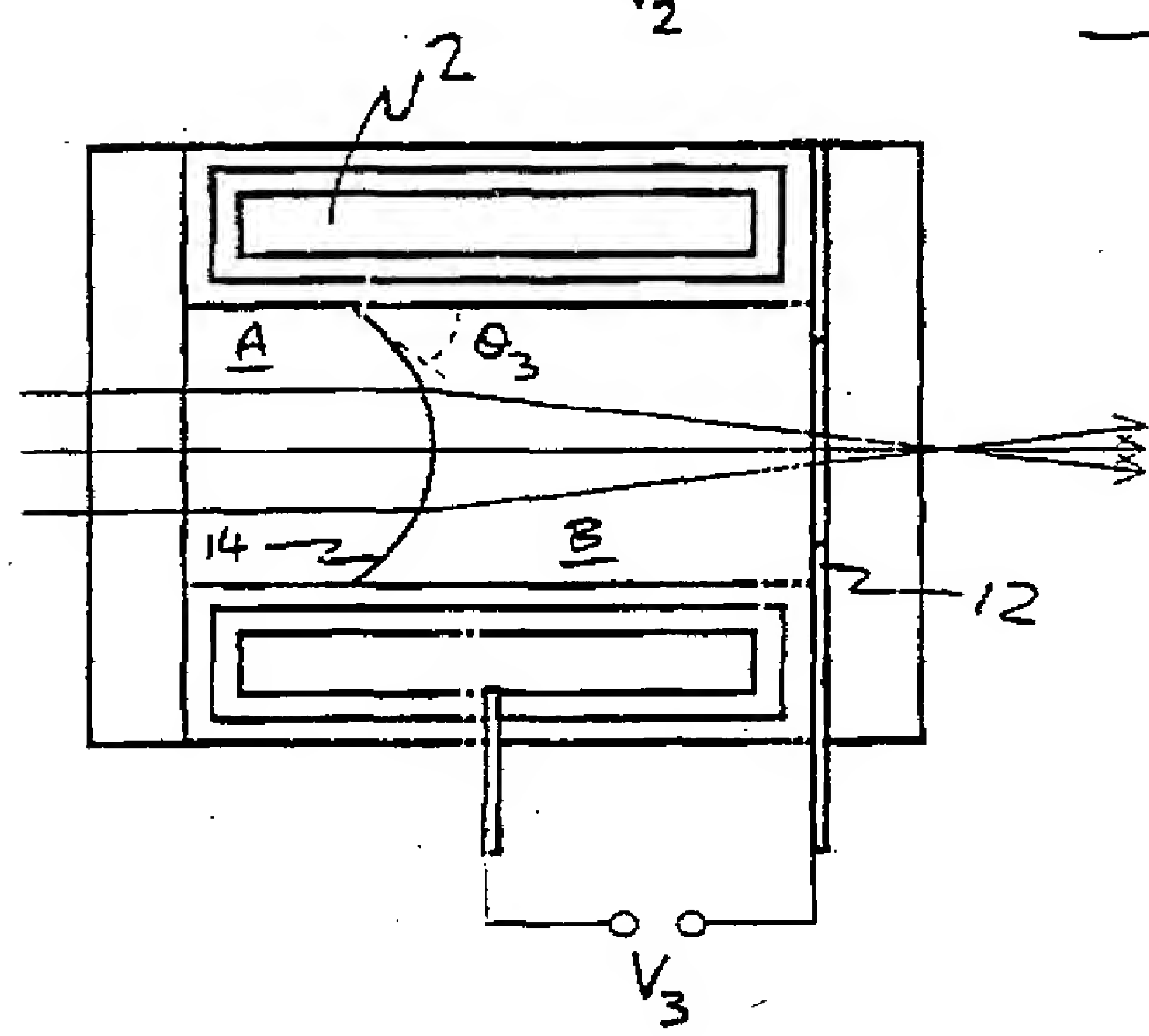

FIG.3